BIOLOGY AND MORPHOMETRY OF THE OCEANIC WHITETIP SHARK, *CARCHARHINUS LONGIMANUS* (CARCHARHINIDAE), OFF NORTH-EASTERN BRAZIL

by

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ABSTRACT. - The oceanic whitetip shark, *Carcharhinus longimanus*, represented 29% of the elasmobranch catch in 197 longline sets conducted off Brazil in the equatorial Atlantic (1°N to 9°S, 30° to 40°W) from 1992 to 1997. A total of 258 individuals were caught (121 males and 137 females) ranging from 71 cm to 250 cm (total length, TL). No significant difference was detected in the length vs eviscerated weight relationship between sexes. Significant differences between sexes were found for twelve morphometric features. Claspers 2.6-21.0 cm in length were found in males measuring 114 to 235 cm. In individuals up to 187 cm, claspers are flexible and smaller than 10 cm. A substantial increment in size of claspers occurred in 190 cm individuals. Testes ranging from 3 to 170 g were recorded in individuals 95 to 235 cm in length and epididymis width varied from 0.4 in to 2.4 cm. In females, nidamental gland width varied between 0.5 to 4.4 cm in 105 to 250 cm. Ovary weights from 5 to 180 g were recorded. Vitellogenic follicles were not observed in females smaller than 180 cm, but in larger individuals they vary from 1.0-4.4 cm. Liver weights ranged from 180 g in a 100 cm female to 7,500 g in a 250 pregnant female. First maturity class is 180-190 cm for both sexes. Three pregnant females (203, 213 and 250 cm in length) were caught with embryos of approximately 20 cm (n = 3), 10 cm (n = 4), and fertilised eggs (n = 9), respectively. Males and females were longer and heavier from July through December. Testis and liver weights in males were also significantly higher during this period. The mean weight of ovaries and follicle diameter decrease during this period which can be attributed to ovulation. A new-born shark caught in August with an unhealed umbilical scar suggested that birth takes place at about 70 cm.

RÉSUMÉ. - Biologie et morphométrie du requin océanique, *Carcharhinus longimanus* (Carcharhinidae) au large du Brésil septentrional.

Le requin océanique, *Carcharhinus longimanus*, a représenté 29% des captures totales d'élasmobranches lors des 197 opérations de pêche effectuées au large des côtes du Brésil entre 1992 et 1997 (1°N to 9°S, 30° to 40°W). Au total, 258 individus (121 mâles et 137 femelles) de 71 cm à 250 cm (longueur totale, LT) ont été pris. Aucune différence dans la relation taille-poids n'a été observée entre les sexes. En revanche douze caractères morphométriques présentaient des différences significatives. Les mâles mesuraient de 114 à 235 cm avec des ptérygopodes de 2,6 à 21,0 cm. Les individus d'une taille < 187 cm avaient des ptérygopodes flexibles < 10 cm; une croissance remarquable de la taille de ces organes a été observée chez les mâles de 190 cm. Des testicules de 3 et 170 g ont été pesés pour des spécimens de 95 à 235 cm, tandis que la largeur des épididymes variait de 0,4 à 2,4 cm au cours du développement. Chez les femelles, les glandes nidamentaires variaient entre 0,5 et 4,4 cm pour des individus de 105 à 250 cm, et le poids des ovaires variait de 5 à 180 g. Aucun follicule vitellogénique n'a été trouvé chez les femelles < 180 cm; chez les spécimens plus grands leur taille variait de 1,0 à 4,4 cm. Une femelle de 100 cm avait un foie de 180 g et une femelle gravide de 250 cm un foie de 7 500 g. La classe de taille à la maturité était 180-190 cm pour les deux sexes. Trois femelles gravides de 203, 213 et 250 cm, portaient des embryons ~ 20 cm (n = 3), ~ 10 cm (n = 4) et des oeufs (n = 9). Les spécimens de plus grande taille ont été capturés de juillet à décembre. Le poids moyen de

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l'ovaire et la taille des ovocytes diminue pendant la période d'ovulation, de juillet à décembre. Un nouveau-né capturé en août et présentant encore la cicatrice ombilicale suggère que la taille à la naissance est d'environ 70 cm.

Key-words. - Carcharhinidae, *Carcharhinus longimanus*, *Carcharhinus maou*, ASW, Brazil, Biology, Morphometry.

The oceanic whitetip shark, *Carcharhinus longimanus* (Poey, 1861), also named *Carcharhinus maou* (Lesson, 1830), is an oceanic epipelagic and ubiquitous species attaining 3 m in total length (TL). It is one of the most abundant oceanic sharks, distributed throughout the world's oceans between 30°N and 35°S, mainly occurring in tropical waters between 20°N and 20°S with temperatures greater than 20°C. Usually occurring well offshore, its catch tends to increase with distance from land (Compagno, 1984).

Common in fisheries carried out off oceanic islands or in areas with narrow continental shelves, accounts of the species in Northern hemisphere have focused on taxonomy (Bigelow and Schroeder, 1948; Springer, 1950; Garrick, 1982; Compagno, 1984, 1988), natural history (Backus *et al.*, 1956; Strasburg, 1958; Fourmanoir, 1961; Gohar and Mazhar, 1964; Lineawear and Backus, 1970; Bass *et al.*, 1973; Guitar Manday, 1975; Cadenat and Blache, 1981; Stevens, 1984; Last and Stevens, 1994; Seki *et al.*, 1998) and age and growth (Seki *et al.*, 1998). A morphometric characterisation of the species from different areas was provided by Garrick (1982).

Despite the commercial importance of the oceanic whitetip shark, the available information on the species in the south-western Atlantic, with few exceptions (Marin *et al.*, 1998), is mostly restricted to secondary literature mentioning abundance indexes or catch compositions (Amorim, 1992; Arfelli and Amorim, 1994; Amorim *et al.*, 1994; Vaske *et al.*, 1995; Lessa and Paglerani, 1997). Recently, a summary of observations on *C. longimanus* embryos caught off south-eastern Brazil (17-35°S), was presented by Amorim *et al.* (1998). However, regarding the equatorial area (1°N-9°S) in the south-western Atlantic, there has been no comprehensive study on the life history and dynamics of local stocks, with exception of an age and growth study presented by Lessa *et al.* (1999).

With samples collected in the Indian Ocean, the Red Sea and in the Pacific Ocean, it was demonstrated that maturity is acquired in both sexes between 175 to 200 cm TL. The species is placental viviparous with litter size increasing with size of female to a maximum of 14-15 embryos, born after a gestation period of about one year, at least in some populations (Gohar and Mazhar, 1964; Bass *et al.*, 1973; Stevens, 1984; Branstetter, 1990; Seki *et al.*, 1998).

A recent survey of pelagic fishes (1992-1997) in the southwestern equatorial Atlantic ocean, within the limits of the Brazilian Exclusive Economic Zone (EEZ), showed that whitetip sharks represented 29% of the total elasmobranch catch, second in abundance only to blue shark, *Prionace glauca* (Linnaeus, 1758). Similarly, data collected from oceanic whitetip shark fins landed by commercial longliners at Natal (Fig. 1) in the northeast of Brazil, showed that this species was the third most abundant overall (pers. obs., 1998).

Since potential variability in life history strategies among different unit stocks (Gulland, 1983) is apparent, some description of the general biology of individuals in the southwestern equatorial Atlantic ocean is required. Furthermore, because only fins and/or

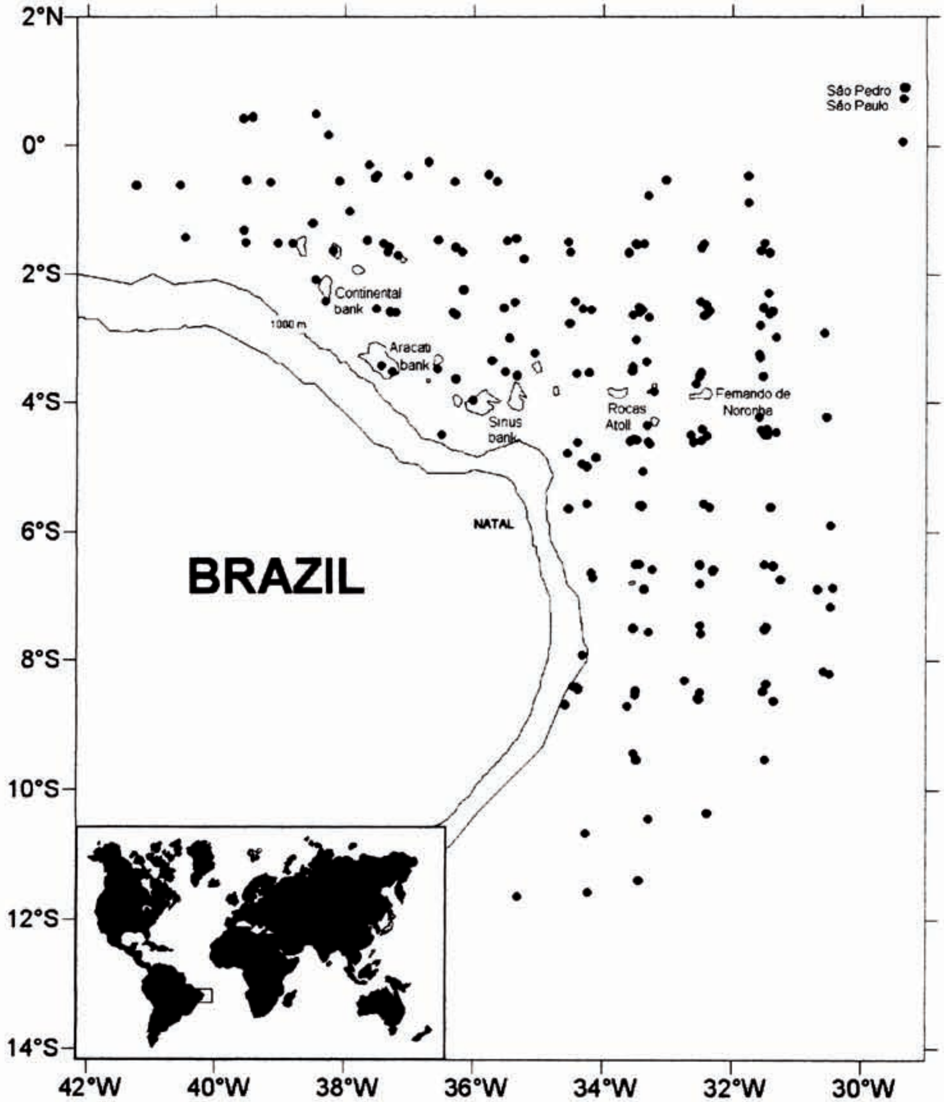

Fig. 1. - Location of the study area (small map) where 258 specimens of *Carcharhinus longimanus* were caught in 197 longline fishing operations from 1992 to 1997.

dressed carcasses are landed at Brazilian ports, information on morphology is needed to index landed catch against total length of fish. Given the above, our specific aims in this paper were to provide original information on general aspects of the life cycle of whitetip sharks in the equatorial Atlantic, including their development, reproduction and morphology.

MATERIALS AND METHODS

This study was done between November 1992 and November 1997 using a research vessel equipped with a traditionally-rigged Japanese-style multifilament longline, 30 km in length with 100 clusters (baskets) with six hooks or 50 12-hook baskets used in alternated sets. Styrofoam buoys, attached to a 25 m line, were tied to a main line after each cluster of 9/0 hooks. The overall calculated depth range for hooks was 60 to 215 m.

A total of 197 sets were performed, all beyond the 1,000 m isobath. The survey was conducted in an area extending from 1°N to 9°S and 40° to 30°W, corresponding to the north-eastern section of the Brazilian Exclusive Economic Zone (Fig. 1). The continental shelf within this area is narrow, with an average distance to the slope (commencing at a depth of 200 m) of 30-48 km. Sea surface temperature ranged between 26 and 28°C.

In all, 258 (121 males and 137 females) oceanic whitetip sharks were captured. Once sharks came on board, an incision behind the head and at the peduncle was done to allow the blood to flow. Therefore, the total length (cm) was measured as the straight line between perpendiculars, from the tip of the nose to the tip of the upper caudal-fin (Garrick, 1982; Branstetter, 1987). Size is expressed throughout the text as total length (TL, cm). Sex, total and gutted weight in both sexes were recorded. Diameter and colour of the largest ovarian follicle, uterus contents (eggs/embryos) and diameter of nidamental glands were taken in females. Testis weight, epididymis width, presence of sperm in smears of seminal ampullae and clasper length measured from the point of insertion at the cloaca to the tip, were recorded in males.

Males were considered to be mature based on the length and calcification of claspers, combined with testis weight and normal sperm (aggregated) in smears of seminal ampullae (Mellinger, 1966). Inferences on female maturity were made according to nidamental gland width, presence of vitellogenic follicles in ovaries and presence of eggs or embryos in the uterus.

Seasonal aspects of reproduction across two semi-annual periods (i.e., January - June and July - December) were evaluated in males and females larger than 180 cm with regard to variation in weight of gonads and liver, length of embryos, clasper length and litter size.

A length/weight relationship $EW = aTL^b$ was calculated, where EW, the eviscerated weight, was used to eliminate any seasonal variation in weight of internal organs.

Fifty-one body and fin features (Table I) were elected among those indicated by Garrick (1982) and Compagno (1984). These, encompassing most of the characters listed by the first author and 50% of those listed by the latter, were considered representative for morphometric characterization. Such features were selected in order to minimize errors in measurements carried out by a number of different collectors. Sharks were eviscerated at sea, so that some features of the trunk indicated by Compagno (1984) were not taken, in order to avoid bias. Measurements were recorded separately for each sex and stage of development (juveniles and adults) and calculations were related to total length. Therefore, comparisons with morphometric studies carried out in different areas by Garrick (1982) were possible. The juvenile sample comprised 33 specimens (14 males and 19 females) ranging from 71 to 179 cm, while the adult sample consisted of 81 individuals (34 males and 47 females), 180 to 250 cm in length. Relationships between features present in carcasses or fins and total length were also performed by simple linear regression whose parameters are presented in table II, for both sexes.

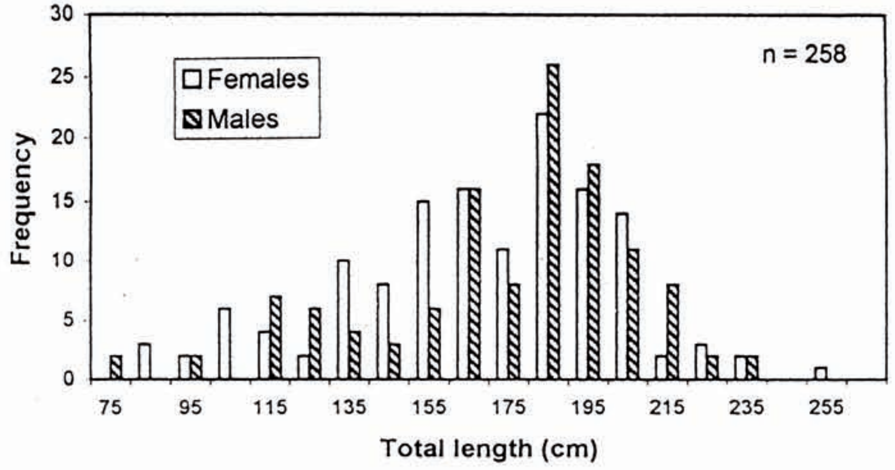

Fig. 2. - Length frequency distribution for *Carcharhinus longimanus* caught off northeastern Brazil.

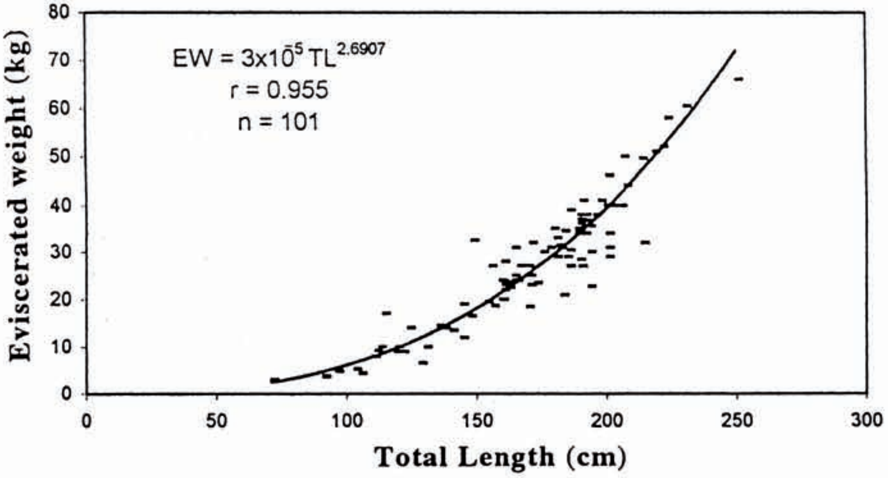

Fig. 3. - Length-weight relationship for both sexes of *Carcharhinus longimanus* caught off northeastern Brazil.

Homogeneity of regression coefficients was determined using the analysis of covariance (ANCOVA). Distributions were compared using Mann-Whitney *U*-tests and Kolmogorov-Smirnov tests (Siegel, 1981). Differences in frequency data between sexes were tested using χ^2 tests with Yate's correction (Browner and Zar, 1984). In all analyses, a significance level of $p < 0.05$ was required for rejection of the null hypothesis (Sokal and Rohlf, 1981).

Table I. - Mean proportions and ranges of 51 features in relation to total length for male and female and juveniles and adults of *Carcharhinus longimanus* off northeastern Brazil. Features with significant differences between sexes are shown in bold.

Features	Juveniles				Adults			
	Males = 14		Females = 19		Males = 34		Females = 47	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Fork length	79.51	75.23-85.00	79.67	73.13-91.22	79.08	70.63-82.50	79.65	67.87-86.45
Snout tip to:								
outer nostrils	**3.36**	**2.52-4.89**	**2.94**	**1.96-4.73**	**2.90**	**1.60-4.57**	**2.98**	**1.79-4.40**
eye	6.87	5.34-9.38	6.48	4.73-8.76	5.93	2.38-8.64	6.24	4.59-8.54
mouth	6.74	5.46-8.15	6.36	3.56-9.12	6.16	4.50-7.03	6.19	4.52-10.98
1st gill opening	16.95	13.42-19.36	17.47	14.46-22.99	16.75	14.71-20.94	16.96	11.29-19.68
3st gill opening	20.18	17.69-22.00	19.65	13.33-27.37	19.54	16.93-22.51	19.91	14.75-22.51
5st gill opening	22.47	19.73-24.18	22.34	19.41-29.20	21.81	18.52-24.32	22.12	16.50-24.86
pectoral origin	21.29	19.46-24.45	21.03	18.18-28.83	20.27	17.94-23.17	20.39	14.75-24.32
pectoral axils	**26.45**	**24.86-28.17**	**26.74**	**21.78-36.50**	**26.03**	**20.21-32.43**	**26.48**	**22.00-30.49**
pelvic origin	49.83	47.48-52.55	51.77	48.06-66.42	50.01	43.92-53.44	51.36	45.74-56.76
1st dorsal origin	31.34	29.23-34.38	32.24	28.89-43.07	30.80	27.78-36.49	31.03	20.06-34.62
2st dorsal origin	62.43	60.34-65.64	63.43	59.52-77.03	62.29	55.56-65.63	62.99	59.69-67.60
anal fin origin	62.26	58.46-65.82	63.10	57.55-77.70	63.14	56.61-67.20	63.93	59.78-69.35
upper caudal origin	71.88	68.46-75.91	73.86	69.42-94.89	72.28	63.49-76.83	72.72	68.59-79.35
lower caudal origin	**71.01**	**66.92-76.00**	**73.05**	**67.77-93.43**	**71.80**	**67.50-74.77**	**72.05**	**68.72-77.74**
Interdorsal space	**21.34**	**19.75-25.54**	**20.92**	**18.16-28.47**	**21.94**	**20.00-23.99**	**21.69**	**19.27-25.20**
Pectoral-pelvic space	**23.77**	**22.27-25.54**	**26.10**	**20.00-40.88**	**25.61**	**21.50-33.23**	**25.76**	**16.50-36.88**
Pelvic-anal space	**7.92**	**3.54-9.83**	**9.79**	**7.02-15.54**	**9.54**	**7.94-14.38**	**8.29**	**6.92-14.53**
Dorsal-caudal space	6.76	6.20-7.07	6.81	5.83-9.12	6.88	4.46-10.41	6.60	5.50-9.47
Anal-caudal space	5.13	4.62-6.52	4.91	3.88-6.93	5.25	3.75-8.65	5.14	4.09-8.65
Nostrils:								
distance between inner corners	5.76	1.41-7.29	6.29	5.35-9.49	5.71	0.78-6.32	5.90	5.23-7.03
Mouth:								
width	9.49	8.32-10.42	9.39	8.14-12.41	9.47	8.06-11.67	9.55	8.47-11.17
length	5.15	4.08-6.25	5.69	4.00-11.90	5.05	3.75-9.77	4.85	3.48-6.02
Eye:								
horizontal diameter	1.47	0.92-1.88	1.30	0.63-1.69	1.01	0.59-1.46	1.00	0.52-1.35
Gill opening lengths:								
1st	4.12	3.26-5.21	4.14	3.04-6.57	3.83	2.97-5.00	3.98	2.92-5.79
3d	4.58	3.45-5.29	4.62	3.80-7.30	4.49	3.24-5.26	4.69	3.66-5.66
5th	3.30	2.55-3.72	3.39	2.86-4.07	3.18	2.43-3.73	3.25	2.34-3.91
1st dorsal fin:								
length of base	11.16	10.53-13.36	11.28	9.52-14.23	10.51	8.99-12.22	10.76	9.20-12.50
length post. margin	14.65	9.24-17.19	16.05	13.89-19.71	13.51	11.26-16.22	14.02	8.29-16.65
length ant. margin	18.75	17.54-19.79	19.01	18.06-21.90	16.19	13.89-19.01	16.49	10.80-18.85
inner margin	**4.85**	**4.23-5.73**	**4.98**	**4.37-6.57**	**4.43**	**3.61-5.29**	**4.62**	**3.20-5.48**
height	**16.52**	**13.38-19.27**	**15.78**	**14.08-18.61**	**13.12**	**11.35-15.34**	**13.78**	**8.00-16.77**

Table I. - Continued.

	Juveniles				Adults			
	Males = 14		Females = 19		Males = 34		Females = 47	
Features	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
2d dorsal fin:								
length of base	3.65	2.17-6.54	3.62	2.91-4.73	3.45	3.06-4.27	3.58	2.95-4.71
length posterior margin	5.09	3.60-6.12	5.16	3.82-7.59	4.87	2.69-8.89	4.93	3.44-6.08
length anterior margin	5.40	2.93-6.25	5.70	4.85-6.74	4.85	4.04-5.79	4.96	3.60-6.14
inner margin	**4.72**	**4.01-6.27**	**4.60**	**3.31-7.34**	**4.04**	**1.12-5.03**	**4.34**	**3.60-5.18**
height	4.07	2.17-5.00	4.14	3.33-5.11	3.68	2.81-4.91	3.85	2.40-4.75
Anal fin:								
length of base	3.66	2.61-4.42	4.01	3.33-5.21	3.70	2.50-4.38	3.80	2.71-4.57
length posterior margin	4.88	3.52-5.70	5.29	4.13-6.94	4.79	3.44-6.03	5.02	3.50-6.88
length anterior margin	6.68	4.35-8.03	7.13	5.76-8.68	6.30	5.50-7.62	6.46	4.30-7.26
inner margin	**4.21**	**3.52-5.00**	**4.16**	**3.39-5.11**	**3.70**	**2.69-4.39**	**3.98**	**2.80-4.88**
height	**5.37**	**2.72-6.25**	**5.30**	**4.07-7.43**	**4.60**	**3.59-6.09**	**4.91**	**1.95-7.01**
Pectoral fin:								
length of base	6.92	5.98-7.66	7.01	4.13-9.12	6.77	5.83-8.75	6.65	0.47-7.77
length posterior margin	22.08	12.50-25.27	23.97	21.43-29.93	21.31	18.74-22.85	22.01	17.60-24.87
length anterior margin	25.47	14.67-28.18	26.51	21.51-32.85	23.33	20.85-25.91	24.38	18.87-27.74
inner margin	5.83	3.80-6.80	6.45	5.56-8.76	5.66	4.25-7.41	5.79	4.40-7.32
Pelvic fin:								
length of base	5.38	4.35-6.80	5.84	4.85-7.43	4.91	3.27-6.08	5.35	3.75-6.50
length posterior margin	**6.79**	**4.35-7.48**	**7.28**	**3.47-9.38**	**6.39**	**5.39-7.81**	**6.87**	**5.76-8.06**
length anterior margin	7.28	3.26-8.84	8.13	6.61-9.49	6.73	5.73-7.95	7.17	5.20-9.27
Caudal fin:								
length of upper lobe	30.20	27.72-32.73	30.83	25.62-40.15	28.99	25.69-31.22	29.46	26.05-32.12
length of lower lobe	14.91	3.85-28.64	16.50	13.78-26.21	14.58	12.20-26.21	14.37	9.15-16.77

RESULTS

Length, sex composition and morphology

A total of 121 males (71-235 cm; mode = 180 cm) and 137 females (83-250 cm; mode = 190 cm) were collected, resulting in a sex ratio of 1:1.13 (males:females). This ratio was not significantly different from 1:1 (χ^2 with Yate's correction = 0.98; df = 1, $p > 0.05$). In addition, Kolmogorov-Smirnov tests failed to detect any significant differences in length frequency distributions by sex (D-max = 0.978, $\chi^2 = 2.393$, df = 2, $p > 0.05$) (Fig. 2). Since ANCOVA showed no significant differences in the relationships between total length and eviscerated weight between sexes ($p > 0.05$), data were combined and a curve fitted ($EW = 3.10^{-5}\ TL^{2.6907}$; n = 101, r = 0.955) (Fig. 3).

Using 51 features, body proportions were calculated and compared by sex within a given developmental category. Significant differences in body proportions were detected in juveniles for 3 features and in adults in 9 features (Table I). Parameters of linear regressions between each feature present in carcasses or fins and total length are shown in table II.

Table II. - Parameters of linear relationships between features of carcass and fins and total lenght for which no differences were found between sexes for *Carcharhinus longimanus* off northeastern Brazil (**A**). Features presenting significant differences between sexes are shown for male and female separately (**B**).

A

Features	a	b	r
Dorsal-caudal space	0.0654	0.1069	0.9245
Anal-caudal space	0.0453	0.617	0.8756
1st dorsal fin:			
Length of base	0.0971	1.7156	0.9233
Length anterior margin	0.1125	9.3807	0.9105
2d dorsal fin:			
Length of base	0.0345	0.1283	0.8926
Length posterior margin	0.0448	0.7318	0.825
Length anterior margin	0.0352	2.5675	0.8159
Height	0.0303	1.3596	0.8012
Anal fin:			
Length of base	0.0367	0.2315	0.9056
Length posterior margin	0.0445	0.8738	0.8042
Length anterior margin	0.055	1.6941	0.9003
Pectoral fin:			
Length of base	0.0637	0.7884	0.9166
Length posterior margin	0.1856	5.7255	0.9222
Length anterior margin	0.1981	7.4973	0.919
Inner margin	0.0473	1.8146	0.8379
Pelvic fin:			
Length of base	0.0483	0.982	0.8731

B

	Males			Females		
Features	**a**	**b**	**r**	**a**	**b**	**r**
Interdorsal space	- 2.6947	0.2350	0.9837	- 4.1664	0.2408	0.9573
Pectoral-pelvic space	- 0.9597	0.2616	0.8911	- 2.8641	0.2698	0.9280
Pelvic-anal space	1.0636	0.0745	0.9176	0.1853	0.0886	0.8763
1st dorsal fin:						
Length posterior margin	8.2888	0.0954	0.8262	6.8825	0.0976	0.8648
Inner margin	1.0751	0.0407	0.8946	1.3939	0.0366	0.9111
Height	8.5257	0.0911	0.8367	6.4078	0.0967	0.8500
2d dorsal fin:						
Inner margin	1.1471	0.0370	0.8240	1.6251	0.0325	0.8799
Anal fin:						
Inner margin	1.4537	0.0313	0.8212	1.6557	0.0278	0.8801
Pelvic fin:						
Length posterior margin	2.5190	0.0549	0.8844	1.0628	0.0583	0.9111
Length anterior margin	3.6500	0.0513	0.8352	1.9656	0.0562	0.8716

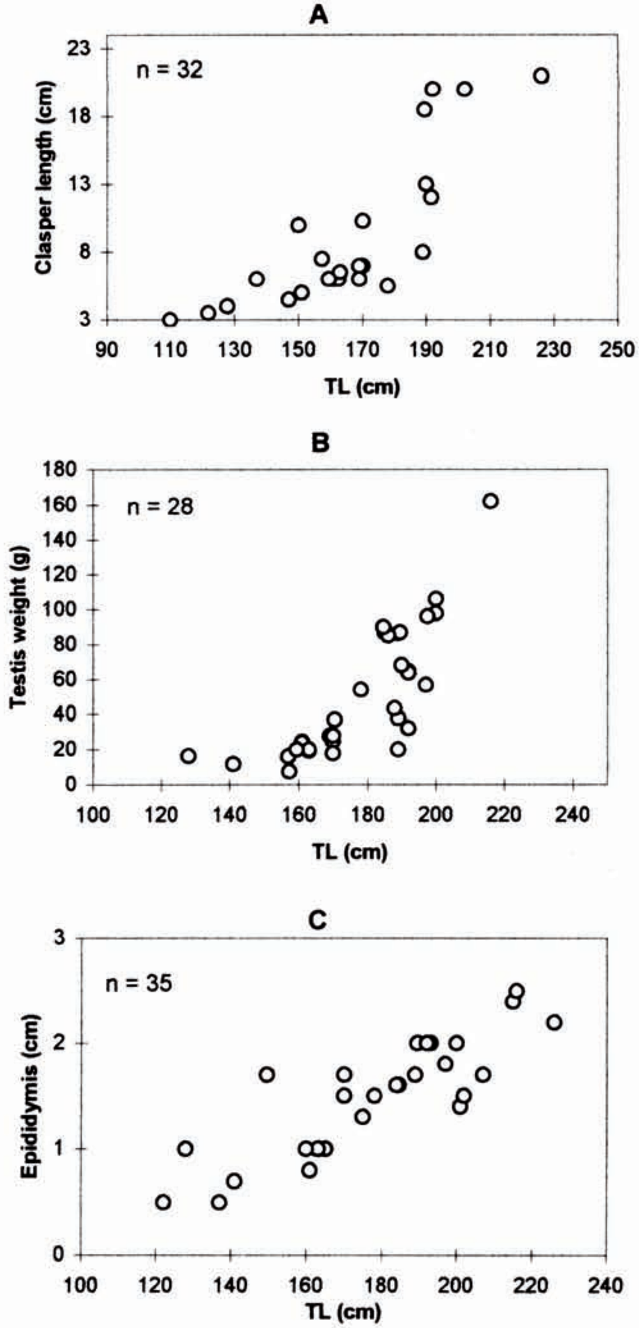

Fig. 4. - Relationships between: (**A**) clasper length and total length; (**B**) testis weight and total length; (**C**) epididymis width and total length for *Carcharhinus longimanus* caught off northeastern Brazil.

Sexual development

Males

Claspers between 2.6 and 21.0 cm were recorded in specimens ranging in size from 114 to 235 cm. No individual less than 187 cm and with claspers smaller than 10 cm showed any evidence of rigid and calcified organs. A greater number of individuals with calcified claspers occurred in sizes larger than 188 cm. A substantial increment in clasper growth (i.e., larger than 10 cm) was observed for individuals between 180 and 200 cm (Fig. 4A).

Testis weight varied from 3 to 170 g in sharks 95 to 215 cm TL. In specimens 130 to 180 cm, testis weight varied from approximately 2 to 60 g, whereas in individuals larger than 180 cm testis weight increased to a maximum of around 170 g (Fig. 4B). Epididymis width varied between 0.4 and 2.5 cm in individuals ranging in length from 120 to 225 cm (Fig. 4C). All individuals longer than 190 cm presented a variable amount of normal sperm in smears. The smallest length-class in which sperm production was observed in smears of seminal ampullae was 160-170 cm. Following Mellinger (1966) and Collenot (1969) this specimen was not considered mature as claspers were not consistent enough to allow the sperm transfer to females.

Liver weight in immature males ranged from 210 g in a 71 cm newborn to 3,000 g in a 189 cm specimen, whereas for adults it varied was from 1,900 g in a 190 cm specimen to 5,100 g in a 217 cm specimen.

Females

Nidamental gland width varied between 0.5 and 4.4 cm in 100 to 250 cm females. Gland width for individuals under 180 cm ranged from 0.5 to 1.4 cm (Fig. 5A). A sharp increase in nidamental gland width (up to 3.5 cm) was observed in the 180-190 cm length class. Individuals 180 to 195 cm in length showed substantial variation in gland width (1.0-3.5 cm). Nidamental gland width increased slowly in specimens larger than 190 cm, reaching 4.4 cm in the largest female (250 cm).

The weight of the functional ovary varied from less than 5 g in individuals smaller than 140 cm up to 180 g in one specimen close to 200 cm in length (Fig. 5B). Vitellogenic follicles were not observed in females smaller than 180 cm. In larger specimens, vitellogenic follicles from approximately 1 to 4 cm in diameter were recorded. The maximum number of large vitellogenic follicles present in any ovary was 12, ranging in size from 2.6 to 4.4 cm. Ovaries containing these large follicles also showed vitellogenic follicles of smaller sizes and white follicles.

Liver weight in females ranged from 180 g in a 100 cm juvenile female to more than 7,500 g in a recently pregnant 250 cm female (not represented in Fig. 5C). Another pregnant female (213 cm in length), bearing embryos smaller than 10 cm, had a liver that weighed 6,000 g, while a third pregnant female bearing embryos 18-20 cm in length had a liver weight of 5,000 g (Fig. 5C).

Seasonality in reproduction

Significant differences were detected in sizes of males and females larger than 180 cm between the two periods, with smaller individuals captured in the first half of the year. Accordingly, eviscerated weights were higher in the second half of the year (Mann-Whitney *U*-test, $p < 0.05$, for both sexes) (Table III).

Mean testis weight in males showed a similar pattern, and was significantly greater in the second half of the year (Mann-Whitney *U*-test, $p < 0.05$), whereas mean

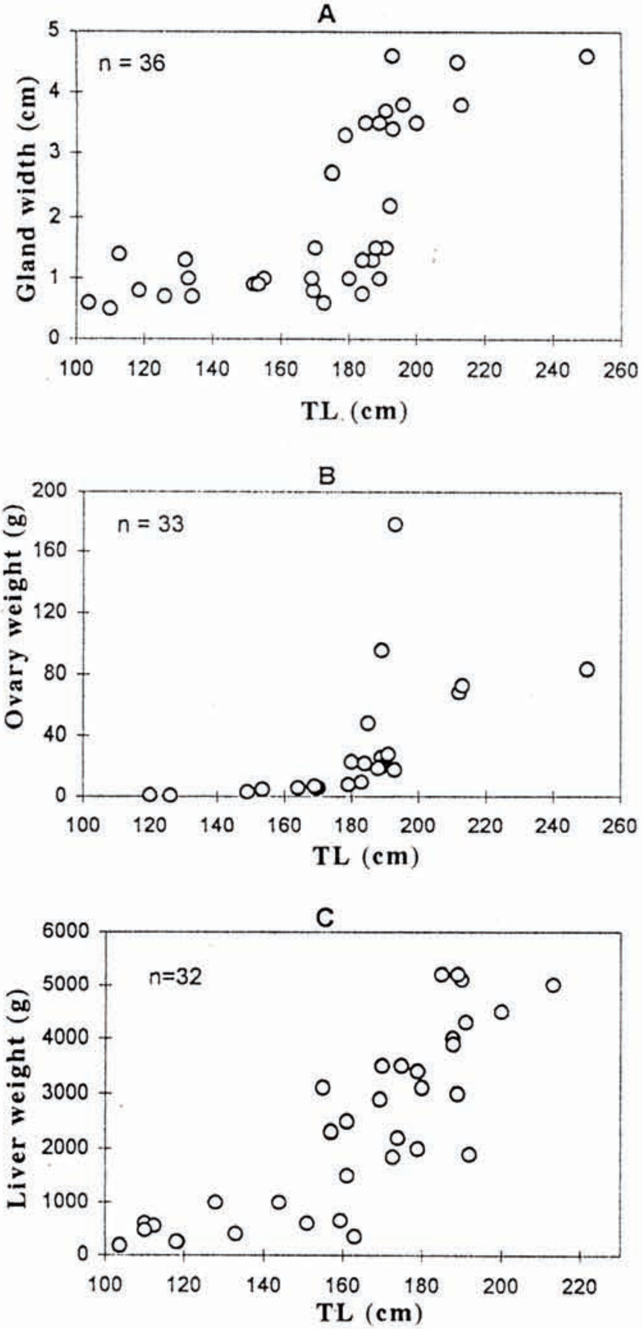

Fig. 5. - Relationships between: (**A**) nidamental gland width and total length; (**B**) ovary weight and total length; (**C**) liver weight and total length for females of *Carcharhinus longimanus* caught off north-eastern Brazil.

weight of liver also showed a similar increase, albeit not statistically significant (Mann-Whitney *U*-test, $p > 0.05$).

The mean weight of ovaries in females was significantly lower in the second half of the year (Mann-Whitney *U*-test, $p < 0.05$), although there was substantial variability about the means. The diameter of the largest vitellogenic follicle showed a similar pattern (Mann-Whitney *U*-test, $p < 0.05$). Significant temporal differences were also detected for liver weight, which was higher in the second half of the year, and embryo sizes, which were higher in the first half of the year (Mann-Whitney *U*-test, $p < 0.05$).

Of the total number of females examined, only three were pregnant with developing embryos or eggs in the uterus. The smallest of these, caught in October of 1995, measured 203 cm and contained 4 embryos, two in each uterus (mean size = 20 cm). Another pregnant female, caught in April of 1994, measured 213 cm and had three female embryos, < 10 cm in length. A third, caught in August of 1995, was 250 cm and had 9 recently fertilized eggs.

A new born male, 71 cm in length, was caught in August, 1996 and had an unhealed umbilical scar, indicating that parturition may have occurred in the study area shortly before.

DISCUSSION

Morphometric analysis, based on body proportions and relationships, is useful for characterizing units of stocks and facilitating the estimation of size compositions based on landed carcasses or fins (Nakano *et al.*, 1997). While some descriptions of such

Table III. - Variations in length (cm), clasper length (cm), testis weight (g), nidamental gland width (cm), ovary weight (g), liver weight (g) and embryo length (cm) considering the two half-years (January-June and July-December) for *Carcharhinus longimanus* off northeastern Brazil. (sd = standard deviation and n = number of specimens).

	Males						
	TL (cm)	**EW (g)**	**Testis (g)**	**Epididymis (cm)**	**Sperm**	**Liver (g)**	**Clasper (cm)**
April-June	195.5	33.4	88.7	2.0	abundant	3.0	13.3
sd	8.8	6.0	31.2	0.2		1.1	4.0
n	12	15	15	15	13	12	15
July-December	201.7	44.4	103.7	2.2	abundant	4.1	15.8
sd	15.2	11.0	57.4	0.37		1.4	4.5
n	14	11	11	11	11	14	14

	Females						
	TL (cm)	**EW (g)**	**Ovary (g)**	**> Ova (cm)**	**Gland (cm)**	**Liver (g)**	**Embryos (cm)**
April-June	191.4	35.0	99.7	2.4	3.8	4275.0	20.0
sd	9.9	9.4	25.5	1.3	0.5	1024.3	2.24
n	12	11	11	11	11	9	4
July-December	209.3	40.7	62.5	1.3	3.0	6060.8	7.5
sd	27.8	13.3	28.6	0.9	0.7	2023.1	2.1
n	16	11	16	16	14	16	3

relationships for oceanic whitetip sharks have been published (Garrick, 1982), they are restricted to other areas and stocks, and do not include specimens from the southwestern equatorial Atlantic ocean. Furthermore, Garrick (1982) showed large variability among different areas, illustrating the need for fishery-specific analysis with a larger number of specimens. Using total weight, length-weight relationships were derived for the species off Cuba (Guitar Manday, 1975) and in the Pacific with significant differences found between sexes (Seki *et al.*, 1998). Such relationships are not really comparable to ours, since eviscerated weights were used and significant differences between sexes were not found. It is suggested that differences by sex and in weights obtained for a given size class, when using the three equations, are due to the bias introduced by the use of total weight.

A strong sexual dimorphism is evident, both in juveniles and adults, indicating that some body features may be inappropriate for indexing against total length. In particular, we detected significant differences in inter-dorsal space, among juveniles and in pelvic-anal space in adults (both features belonging to the carcass). Significant differences were also found for features related to the first and second dorsal fins, anal fin, and pelvic fins. All of these features, therefore, should be avoided during sampling. However, considering that inter-dorsal space is generally the most common measurement recorded during sampling, relationships for juveniles and adults can be applied as long as sex is known (Table II). Also, while some features of fins may be considered reliable estimators of body size, these should be recorded soon after the fins are removed, since it is known that they lose weight and shrink during desiccation (Rose, 1996).

The sample of the oceanic whitetip sharks examined in the present study is the first from the southwestern equatorial Atlantic and comprised a large number of juveniles (over 70% of total catch). A 71 cm newborn male represented the smallest free-living specimen recorded to date, with another seven individuals smaller than 105 cm. The relatively low frequency of small individuals throughout the catch is similar to size distributions recorded in previous studies. For example, Maul (1955) collected one 94 cm female off Madeira. Backus *et al.* (1956) collected one 102 cm specimen in the northwestern Atlantic, Strasburg (1958) recorded 80 to 100 cm specimens in the central Pacific, Stretta *et al.* (1996) recorded two specimens 93 and 88 cm in eastern Atlantic (Guinea) and Indian Oceans, respectively, and Amorim *et al.* (1998) recorded 80-84 cm juveniles off southeastern Brazil. Bass *et al.* (1973) proposed that the scarcity of free-swimming specimens under 100 cm in catches was probably due to spatial variation in sizes of individuals and the inaccessibility of nursery areas by commercial fishers. Given that the umbilical scar on the smallest free-swimming specimen (71 cm) captured in the present study had not completely healed, birth size in the southwestern equatorial Atlantic may occur at around 70 cm, close to the maximal embryo size (69.7 cm) recorded off southeastern Brazil (Amorim *et al.*, 1998). This size at birth is similar to that postulated by Bigelow and Schroeder (1948) and slightly greater than the 60-65 cm suggested by Bass *et al.* (1973) and Garrick (1982).

Bigelow and Schroeder (1948) measured a 350 cm specimen and suggested that individuals of this species may reach 395 cm. The maximum sizes recorded to date, however, have been much lower and are comparable to the largest in the present study (i.e., 250 cm). For example, specimens 270 cm were caught in the southwest Indian Ocean and off Australia (Bass *et al.*, 1973; Stevens, 1984), whereas specimens ranging in size from 240 to 270 cm were captured in the northwestern Atlantic (Backus *et al.*, 1956) and Pacific (Saika and Yoshimura, 1985; Seki *et al.*, 1998), Indian, and eastern Atlantic oceans

(Stretta *et al.*, 1996). Bass *et al.* (1973) indicated that specimens over 300 cm would be the exception rather than the rule.

Since there appears to have been some reduction in the size of individuals captured over the past 50 years (Bigelow and Schroeder, 1948; Bass *et al.*, 1973; Stevens, 1984), and the species is subjected to extensive fishing effort (Compagno, 1984; Taniuchi, 1990; Hazin, 1990; Bonfil *et al.*, 1994; Amorim *et al.*, 1998) which is expected to increase in the future, studies on population structures and dynamics, which have received little attention, (Compagno, 1984), are warranted.

Overall, maturity occurs between 180 and 200 cm, although most individuals mature at 180-190 cm, considered as the first maturity class for both sexes. In males, at this size class claspers were rigid, varying from ~ 8 to > 20 cm, and females had ovaries heavier than 80 g, with glands > 2 cm. Rigid claspers, together with the presence of sperm are requirements for first maturity determination in males (Mellinger, 1966; Collenot, 1969). As such, a specimen measuring 160 cm that presented sperm in seminal ampullae and, uncalcified claspers, was considered as immature. Contrasting, Seki *et al.* (1998) observed claspers > 18 cm in one 156 cm specimen and concluded that maturity occurs between ~156 to ~ 195, with most males maturing at 175-189 cm in the Pacific population. Excluding the precocious male mentioned by these authors, maturity sizes do not greatly differ between the two considered stocks.

Discontinuities (interpreted as the point of inflexion of a exponential curve where the organ development changes with the onset of maturity) were observed in several organs in females at around 180 cm. Also, vitellogenic follicles ~1 cm in diameter were measured in individuals of this size. The number of pregnant females was rather low and additional sampling is required to determine the gestation period in the study area.

Even if maturity sizes, on the whole, seem do not greatly differ between stocks from the Pacific and equatorial Atlantic, Seki *et al.* (1998) estimated that maturity corresponded to 4-5 years old individuals. These results do not agree with ours, where the age at maturity corresponded to 6-7 year old specimens (Lessa *et al.*, 1999). These differences may be a consequence of faster growth rates in the Pacific, thus corroborating the assumption of different stocks.

Regarding maximum litter size, Gohar and Mazhar (1964) recorded 10 to 15 embryos, Seki *et al.* (1998) recorded 14 embryos, and we recorded three litters of 3 and 4 embryos and 9 eggs. Bass *et al.* (1973) found a positive correlation between female size and number of embryos when combining data from several studies. Overall, following Branstetter (1990) the number of embryos for oceanic whitetip sharks is low.

In terms of seasonality, in Northern Hemisphere birth and mating probably occur in spring (May) or early summer (June) (Backus *et al.*, 1956; Gohar and Mazhar, 1964), while in Southern Hemisphere Bass *et al.* (1973) found near-term embryos during September and October (winter/spring) and Amorim (1998) found full term embryos (63.0-69.7 cm) from July to November (winter/spring). In the present study, a newborn and a recently fertilized female were caught in August (winter). Year-round variations in several organs in both males and females also seem to suggest the existence of a relatively well defined cycle. Catches from July to December contained larger females and males, which showed heavier livers and testes, respectively, and there was a decrease in follicle diameter and ovary weight in females from July to December. These observations contrast somewhat with those for the Northern Hemisphere and seems to reinforce the idea of different stocks.

We have shown that commercial exploitation of oceanic whitetip sharks mainly involves juveniles and that like most elasmobranchs, oceanic whitetip sharks have a life history strategy marked by traits that may render the species highly vulnerable to overfishing in the southwestern equatorial Atlantic. Future research needs to include more detailed examination of the current level of exploitation and the development of appropriate models to determine sustainable effort and catch levels. Given the evidence presented here to show that it may be feasible to accurately index features of fins against total length, regular samples need to be collected to monitor size compositions of commercial catches.

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